/CDF/ANAL/EXOTIC/CDFR/6436

Searches for First Generation Leptoquarks in the eνjj channel

Simona Rolli

TUFTS University

Abstract

We report on a search for first generation scalar leptoquarks, done using 72.0 pb^{-1} of run II data taken at $\sqrt{s}$ = 1960 GeV. Leptoquarks are assumed to be pair produced and to decay into a lepton and a quark of the same generation. We will focus on the signature represented by one energetic electron, missing energy and two jets. We set an upper limit at 95% CL on the production cross-section as a function of the mass of the leptoquark. By
Assuming ($\beta = Br(LQ \rightarrow eq)$) = 0.5 and using the NLO theoretical estimate we reject the existence of scalar leptoquarks with mass below 177 GeV/c^2 .

Introduction

Leptoquarks are hypothetical color-triplet particles carrying both baryon and lepton quantum numbers and are predicted by many extension of the Standard Model as new bosons coupling to a lepton-quark pair[1]. Their masses are not predicted. They can be scalar particles (spin 0) or vector (spin 1) and at high energy hadron colliders they would be produced directly in pairs, mainly through gluon fusion or quark antiquarks annihilation. In figure 1 a typical production diagram is reported.

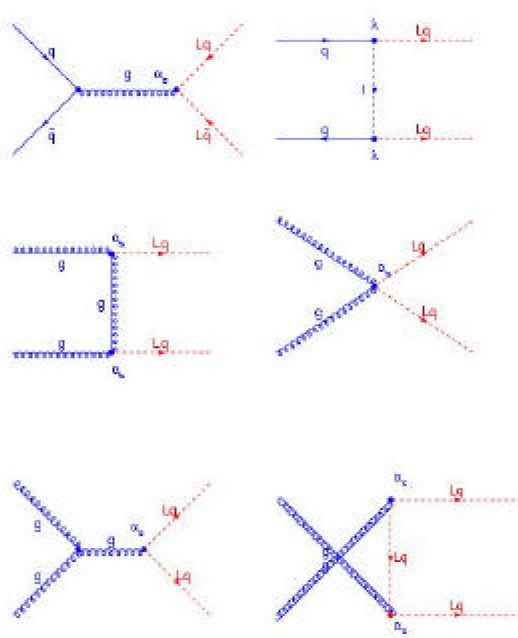

Figure 1

The couplings of the leptoquarks to the gauge sector are predicted due to the gauge symmetries, up to eventual anomalous coupling in the case of vector leptoquarks, whereas the fermionic couplings λ are free parameters of the models. In most models leptoquarks are expected to couple only to fermions of the same generations because of experimental constraints as non observation of flavor changing neutral currents or helicity suppressed decays. The production cross section for pair produced scalar LQ has been calculated up to NLO[1].The decay angular distribution of scalar leptoquarks is isotropical. The NLO cross section at $\sqrt{s}$ = 1960 GeV is reported in Table 0 for values of the LQ mass between 200 and 320 GeV/c^2. The scale has been chosen to be $Q^2 = M_{LQ}^2$ and the set of parton distribution functions is CTEQ4M[].

M_{LQ} (GeV/c^2)	σ(NLO) [pb]
200	0.265E+00
220	0.139E+00
240	0.749E-01
260	0.412E-01
280	0.229E-01
300	0.129E-01
320	0.727E-02

Table 1 –*Theoretical cross section for pair production of LQ at Ös = 1960 GeV. Q = m(LQ)*

The cross section compared with the one at 1.8 TeV is reported in Figure 2

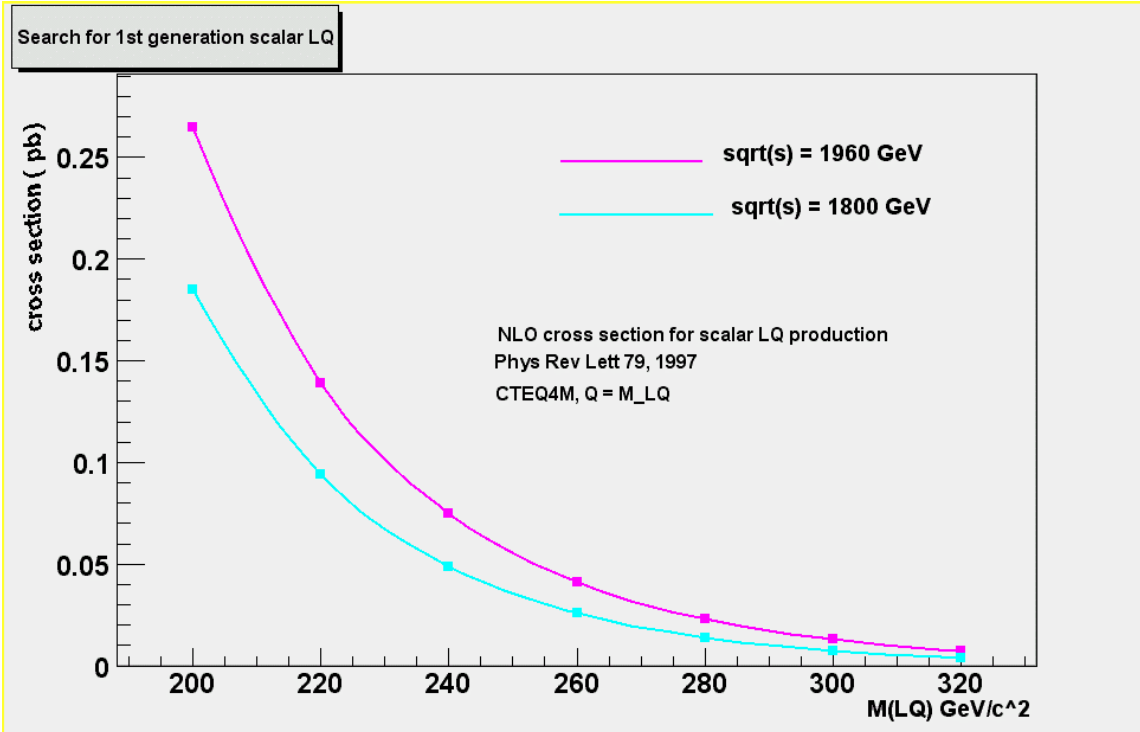

Figure 2

This analysis is focused on the search for first generation scalar leptoquarks S1, pair produced and decaying into eνjj. The analysis strategy is a variation of the run I analysis[2,3] , with a few modification: the jet energy cut has been increased for the second jet, as we are probing higher leptoquarks mass and a missing energy significance cut has been place to reduce the background.

Current Limits

In table 1 the current limits on the first generation LQ are reported, both from CDF and D0.

1st Gen	β	Scalar (GeV/c^2)	Vector –minimal coupling(GeV/c^2)	Vector – Yang-Mills coupling(GeV/c^2)
D0	1	225(242)	292	345
	0.5	204	282	337
	0	98	238	298
CDF	1	220 (242)	280	330
	0.5	182	265	310

Table 2 – *current limits on first generation LQ from the TeVatron*

Data sample and electron identification

The data sample used for this analysis is *btop0g* (inclusive electrons) stripped for the Top group from the inclusive high pt electron datasets. The sample is described in[4].
The L3 trigger dataset *(bhel08*) was reconstructed with offline version 4.8.4 and the events were filtered into *btop0g* using the following loose cuts:

- CdfEmObject.Pt > 9.0 GeV
- CdfEmObject.etCalMin > 18.0 GeV
- CdfEmObject.delX < 3.0
- CdfEmObject.delZMin < 5.0
- CdfEmObject.E/P < 4.0
- CdfEmObject.lshr < 0.3
- CdfEmObject.hademMax < 0.125

For the ELE_70 trigger:

- CdfEmObject.Pt > 15.0 GeV
- CdfEmObject.etCalMin > 70.0 GeV
- CdfEmObject.delX < 3.0
- CdfEmObject.delZMin < 5.0

A REMAKE version of *b0topg* was made where all the calorimeter-dependent objects were dropped in input as well as electron and muon reconstruction objects. The 4.8.4 tracks were refitted (using TrackRefitModule) without L00 hits, and electron and muon objects were remade picking up the refit tracks and run-dependent calorimeter corrections. The sample is on fcdfsgi2 in */cdf/data54/ewk/data/highpt_491/Inclusive-ele_484_REMAKE* and corresponds to an integrated luminosity of 70.2 pb^{-1} (good runs between March 23 – January 12, 2003 – runs 141544 to 156487, selected following the *good run list without Silicon* used by the W mass group).

The sample has been reduced by requiring events with at least 1 CdfEmObject (with trackid != 0), satisfying the following criteria:

- E_T > 25 GeV
- p_t > 10 GeV
- hadem <= 0.055 + 0.00045 * E
- E/p < 4 (for E_T < 200 GeV)
- |DeltaX | < 3.0 cm
- |DeltaZ | < 5.0 cm
- lshr <= 0.2

- fiducial == 1
- isolation ratio < 0.1 (tight electron)

These electron identification cuts are also used in the Z' [5,6] analysis and the efficiencies are reported in Table 3.

CDF Run II Preliminary (72 pb^{-1})

Cut	Number of candidate events	Number of background	Efficiency (%)
$Iso < 0.1$	2101	118	97.7 ± 0.2
$Iso < 0.2$	2329	274	99.6 ± 0.1
$E_{had}/E_{em} < 0.055 + 0.00045 \times E$	2532	496	99.1 ± 0.2
$E/P < 4.0$ (for $E_T < 200$)	2732	700	99.0 ± 0.2
$\lvert\Delta X\rvert < 3.0$	2808	804	98.2 ± 0.2
$\lvert\Delta Z\rvert < 5.0$	2902	858	99.3 ± 0.1
$L_{shr} < 0.2$	2482	406	100.0 ± 0.1
Tight central overall(ε_T)	1717	36	89.6 ± 0.5
Loose central overall(ε_L)	1787	46	91.2 ± 0.5
$\varepsilon_{CC}(= 2 \cdot \varepsilon_T \cdot \varepsilon_L - \varepsilon_T^2)$			83.2 ± 0.8

Table 3 – *Efficiency for CC electrons as from ref[5,6]*

Acceptance calculation

We generated 5000 events samples of scalar leptoquarks pair decaying one into eq and the other into *nq* for M_{LQ} in the range 160 to 280 GeV/c^2 using Pythia[10]. The samples have been generated to simulate realistic beam conditions, emulating run number 151435 and using the following talk-to for the full beam position:

```
talk GenPrimVert
  BeamlineFromDB set false
  sigma_x        set  0.0025
  sigma_y        set  0.0025
  sigma_z        set 28.0
  pv_central_x   set -0.064
  pv_central_y   set  0.310
  pv_central_z   set  2.5
  pv_slope_dxdz  set -0.00021
  pv_slope_dydz  set  0.00031
exit
```

The samples were generated with $Q^2 = M_{LQ}^2$ and the MRS-R2 pdf set[12]. The samples were simulated with cdfSim version 4.9.1 and Production 4.9.1 was ran on them.

In figure 3-5 the E_T distributions of the decay products of the Leptoquark are plotted, for different values of the mass of the leptoquark and compared to the major sources of background.

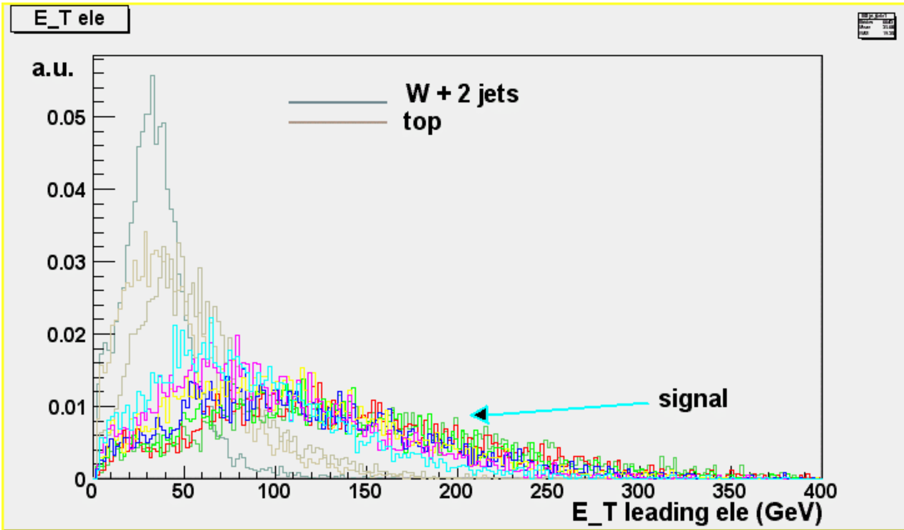

Figure 3

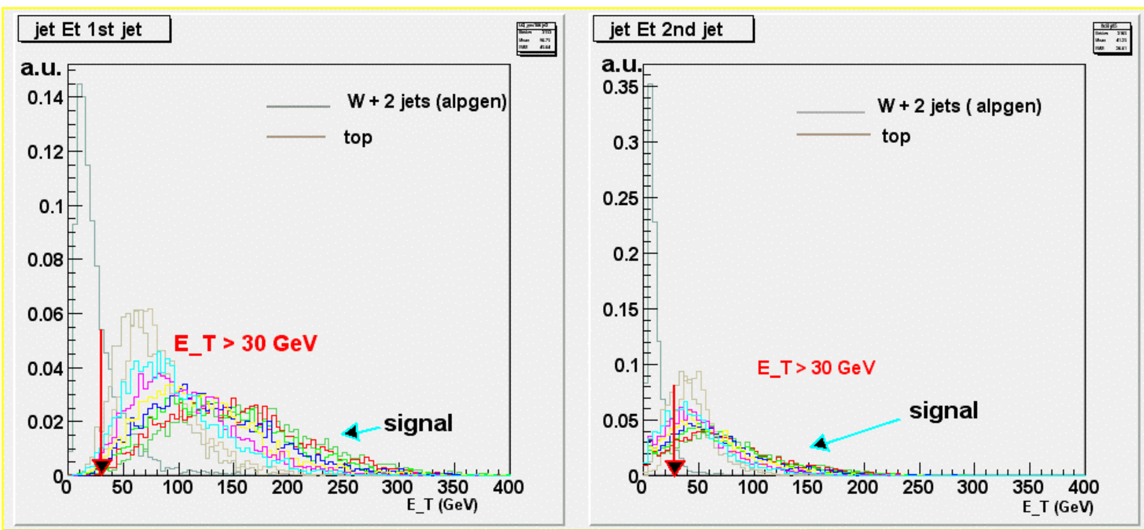

Figure 4

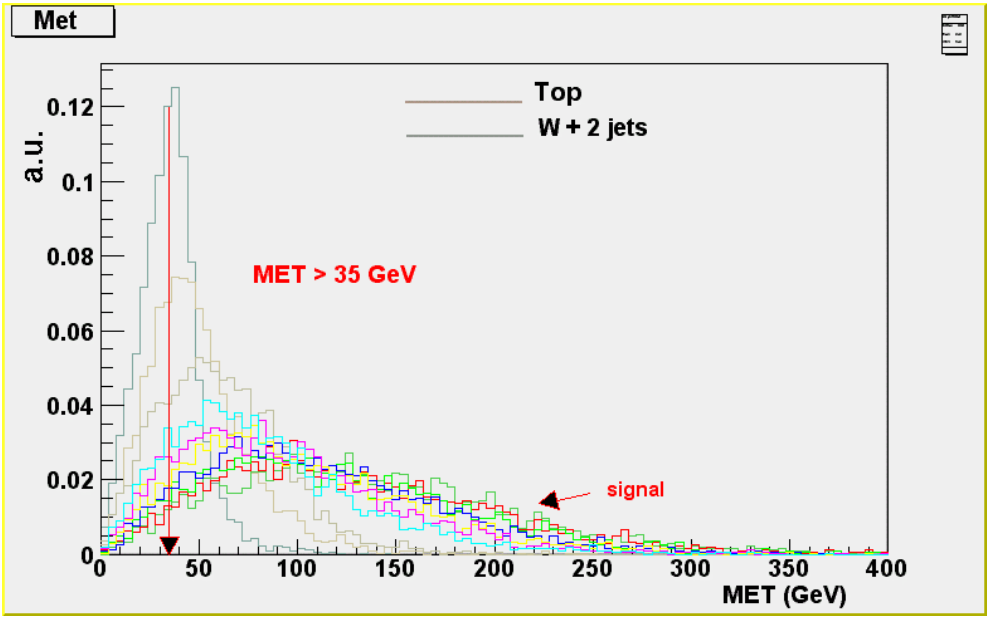

Figure 5

The analysis cuts are a variation of the previous Run I analysis:

- 1 electron with $E_T > 25$ GeV , satisfying tight ID cuts;
- 2 jets with $E_T(j1) > 30$ GeV
- $\Delta\phi$ (MET-jet) > 10°
- $E_T(j1) + E_T(j2) > 80$ GeV
- $M_T(e-\nu) > 120$
- $Met/\sqrt{\Sigma E_T} > 4.5$

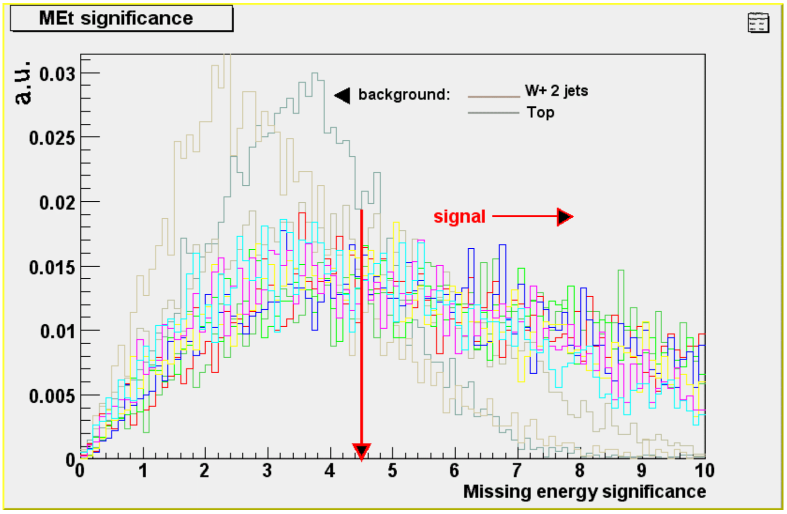

Figure 6

The analysis cuts efficiencies are calculated relatively to the number of events having 1 cdfEmObject1 with track id different from 0 (to exclude photons), matching the generator level electron. They are reported in Figure 7 and Table 4. The efficiencies are then folded with the electron ID efficiencies reported in Table 2, the z vertex cut efficiency[7] (0.952 ±001 (stat) ±005 (sys)) and the trigger efficiency[9] (0.991 ±001) .

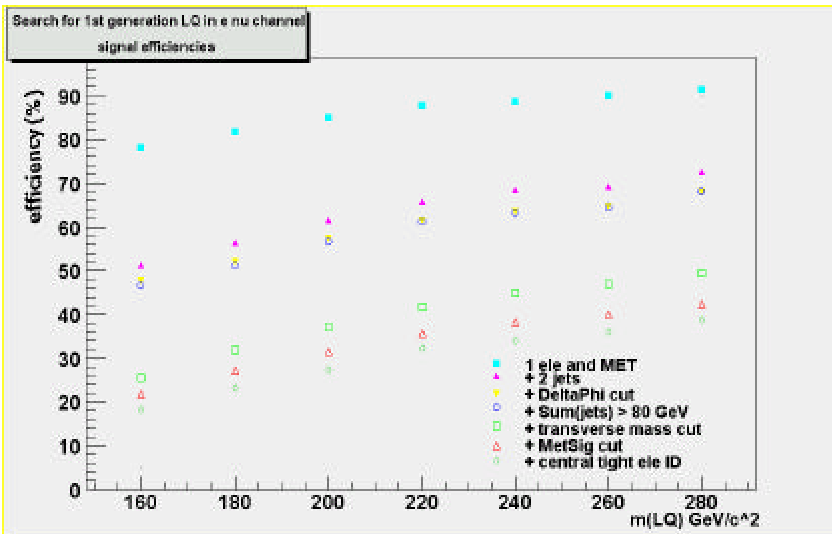

Figure 7 – *kinematical efficiency as function of the leptoquark mass*

M_{LQ} (GeV/c^2)	160	180	200	220	240	260	280
1 ele with E_T > 25 GeV and MET > 35 GeV	0.78±0.006	0.816±0.005	0.850±0.006	0.877±0.005	0.884±0.005	0.898±0.005	0.913 ±0.004
2 jets with E_T > 30 GeV	0.512±0.008	0.564±0.008	0.614±0.008	0.656±0.007	0.684±0.007	0.691±0.007	0.725± 0.007
$\Delta\varphi$(jet-MET) > 10°	0.475±0.008	0.520±0.008	0.574±0.008	0.614±0.008	0.634±0.007	0.645±0.007	0.680± 0.007
$\Sigma(E_T(ele_i))$ > 80 GeV	0.464±0.007	0.510±0.008	0.564±0.008	0.611±0.008	0.631±0.007	0.643±0.007	0.679± 0.007
M_T(e-ν) > 120 GeV/c^2	0.254±0.007	0.318±0.007	0.369±0.007	0.418±0.008	0.449±0.008	0.469±0.008	0.495± 0.008
Met/$\sqrt{\Sigma E_T}$ > 4.5	0.18±0.006	0.223±0.007	0.262±0.007	0.312±0.007	0.332±0.007	0.353±0.007	0.379± 0.008

Table 4 - *kinematical efficiency as function of the leptoquark mass*

The expected number of events of signal in 72 pb^{-1} given the above efficiencies and the NLO theoretical cross section for different value of the renormalization/factorization scale, is reported in the Table below:

Mass (GeV/c^2)	n Theory CTEQ4M (pb) $Q^2 = M^2_{LQ}/4$	n Theory CTEQ4M (pb) $Q^2 = 4M^2_{LQ}$
160	7.8	6.2
180	4.8	3.8
200	2.8	2.3
220	1.7	1.4
240	0.99	0.8
260	0.57	0.5
280	0.34	0.3

Table 5 – *Expected number of signal events in 72 pb^{-1}*

After our selection cuts 1 event is left. In Table 5 we report the number of events surviving each kinematical cut.

Number of events with one tight electron and MET > 35 GeV	26413
2 jets with E_T > 30 GeV	224
$\Delta\phi$(MET-jet) > 10°	176
$E_T(j1) + E_T(j2) > 80$	136
M_T (e-ν) > 120 GeV/c^2	23
$Met/\sqrt{\Sigma E_T} > 4.5$	1

Table 5 – *List of events passing the selection cuts*

Backgrounds

The main backgrounds is due to W→eν events accompanied by jets due to radiation. The main component of this background is eliminated by cuts on M_T of the electron and neutrino and the $Met/\sqrt{\Sigma E_T}$ cut. We studied the distribution of this background by generating the process W + 2 jets with Alpgen[11] and using the MC parton generator mcfm[13] to obtain the NLO cross section.
Another source of background is represented by tt production where both the W decay into eν and one lepton is mismeasured and the decay of the top pair into lepton + jets. Other backgrounds from fake electrons or tau decays are expected to be negligible due to the electron isolation and large electron and jet transverse energy requirements and are not considered here. The expected number of W + 2 jets events in 70.2 pb^{-1} is 1.55 ±0.8. The expected number of tt events is 0.37±0.03 events. To normalize simulated events to data we used the theoretical cross section for tt, σ(tt)×Br(W→eν) = 0.0739 pb (dilepton),

$\sigma(tt)\times Br(W\rightarrow e\nu, W\rightarrow qq)$ = 0.21 pb and the theoretical cross section for W + 2 jets from mcfm.

The total number of expected events of background is 1.90 ± 1.33.

We also checked that the events we are left before requiring 2 jets and the subsequent analysis cuts are consistent with the production of W.
W boson candidates are selected by relaxing the MET cut to 25 GeV (so that we can compare to the official W cross section analysis) and the cross section is calculated from the following formula:

$$s\ !Br\ (pp\rightarrow W\rightarrow \nu e) = (N_W-N_{BG})/(A_Z\times\varepsilon_{ID}\times\varepsilon_{trig}\times\varepsilon_{z0}\times L)$$

Using the values listed in the Table below (cdfnote 6300, extrapolated to the increased luminosity) we obtain for the W cross section a value of 2.93± 15.3 nb. In Figure 8 the W mass distribution is plotted.

Acceptance	24.6 ± 0.04 (stat) ± 1.05(sys) %
ID efficiency	86.4 ± 0.5%
Trigger Efficiency	99.9 ± 0.1%
z_0 efficiency	95.2 ± 0.5%
Observed number of events	44510 ± 100 (stat) ± 900 (sys)
Estimated background	2590
Integrated Luminosity	72. ± 4.32

Table 6 – *parameters used in the calculation of the W cross section*

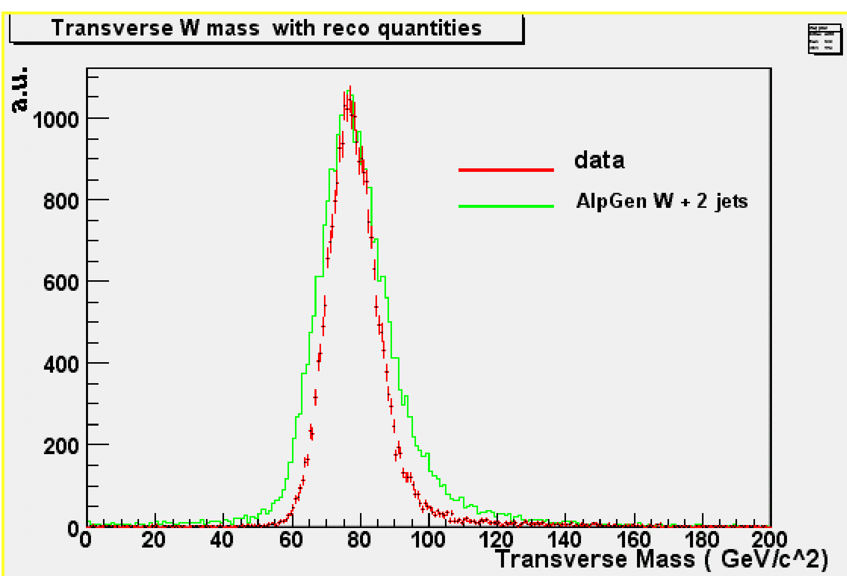

Figure 8 – *Transverse mass distribution for MC and data. Data and generated MC have been normalized to each other to take into account the different luminosity. No jets requirement and successive LQ analysis cuts have been applied to this event selection*

Systematic Uncertainty

The following systematic uncertainty is considered:

- Luminosity: 6%
- Acceptance
  - pdf 4.3% (from run I)
  - statistical error of MC 2.2%
  - Jet energy scale < 1%
- Electron ID efficiency[5,6]
  - statistical error of $Z \rightarrow e^+e^-$ sample: 0.8%
  - energy scale : 3.7%
- Event vertex cut : 0.5%[7]

Adding the above systematic uncertainty in quadrature will give a total systematic uncertainty of about 8.5%. The total relative uncertainty on the acceptances is then about 9%.

Cross section Limit

The production cross section σ of the process S1S1$\rightarrow$ eejj can be written as follows:

$$\sigma\times 2\times Br(LQ\rightarrow ej)(1- Br(LQ\rightarrow ej)) = \sigma\times 2\times\beta\times(1-\beta) = N/(\varepsilon\times L),$$

where N is the number of observed events on data after our selection, ε is the total selection efficiency as a function of M_{LQ} and L is the integrated luminosity. As we found no candidate events in our selection, we set a 95% C.L. upper limit on the cross section as a function of M_{LQ} defined as:

$$\sigma^{lim} = N^{lim}/(\varepsilon\times L\times 2\times\beta\times(1-\beta))$$

The limit was calculated using the bayes code[14].

In Table 7 we report the values of the limit cross sections in eνjj for each M_{LQ} and for β = 0.5 and the theoretical calculations at NLO for pair production of scalar LeptoQuarks at the TeVatron done using CTEQ4M pdf and for different choices of the scale. In Figure 8 the limit cross-section as function of M_{LQ} is compared with the theoretical expectations for β = 0.5. At the intersection point between experimental and theoretical curves we find the lower limit on M_{LQ} at 177 GeV/c^2.

Mass (GeV/c^2)	95%CL σ (pb)	σ Theory CTEQ4M (pb)	σ Theory CTEQ4M (pb)
		$Q^2 = M^2_{LQ}/4$	$Q^2 = 4M^2_{LQ}$
160	0.32	0.59	0.47
180	0.25	0.28	0.23
200	0.21	0.14	0.12
220	0.18	0.07	0.06
240	0.17	0.04	0.03
260	0.16	0.02	0.02
280	0.15	0.01	0.01

Table 7 – *Values of the upper limits at 95% CL of the production cross section of first generation leptoquarks decaying into* $e\nu jj$ *channel as a function of* M_{LQ}. *The last 2 columns on the right report the result of the theoretical calculations at Next-To-Leading order with CTEQ4M for different choices of the scale, multiplied by a factor* $2\beta\times(1-\beta)$.

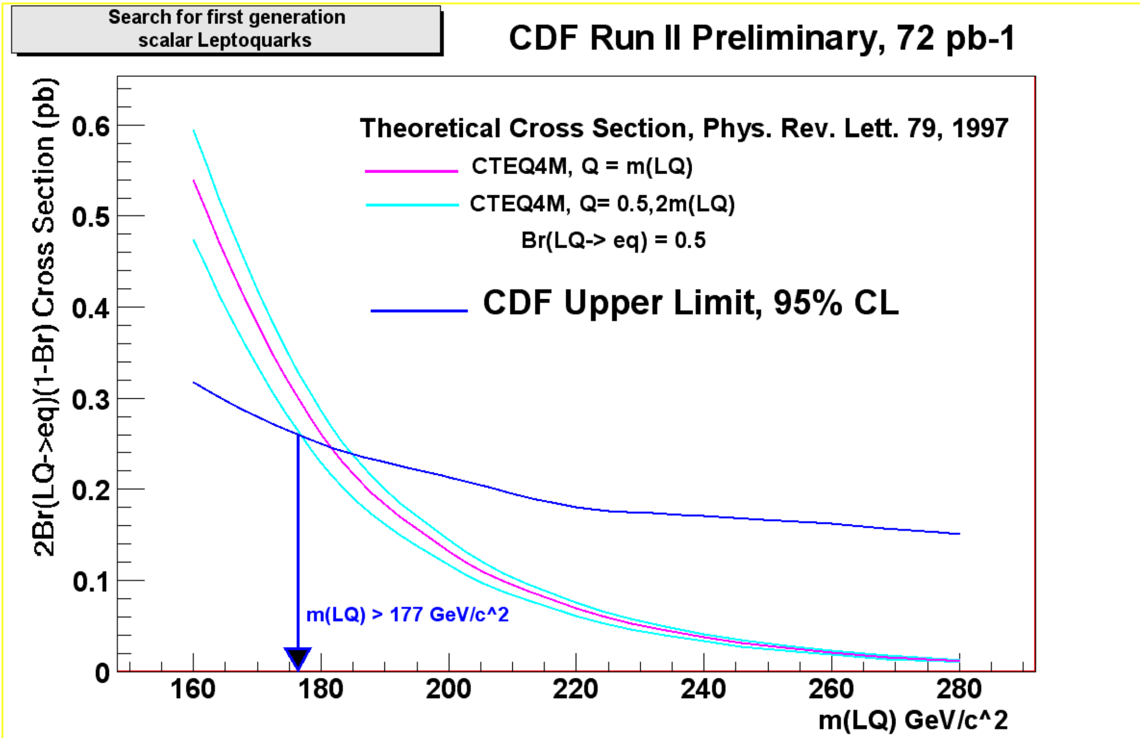

Figure 8 - *Limit cross section as a function of M_{LQ} compared with the theoretical expectations calculated at NLO accuracy. At the intersection points between experimental and theoretical curves we find a lower limit on M_{LQ} at 187 GeV/c^2*

Conclusions

We have presented a preliminary 95% CL cross section lower limit as a function of M_{LQ}, for leptoquarks decaying with 50% branching ratio into eq and we have compared it to the theoretical predictions for leptoquark pairs production at the TeVatron. By using the theoretical estimate, we can reject the existence of a scalar leptoquark with mass lower than 177 GeV/c^2 for $\beta = 0.5$

Acknowledgements

I want to thank Federica Strumia and Carla Gross-Pilcher for various comments and suggestions regarding the run I analysis. I also want to thank Stephan Lammel for the patience he showed when answering my many questions…

References

1) Pair Production of scalar LeptoQuarks at the TeVatron, M. Kramer et al., Phys Rev Lett 79, 341, 1997.
2) Search for first generation leptoquarks pair production , A. Amadon, C. Grosso-Pilcher and F. Strumia, CDF/ANAL/EXOTIC/CDFR/4126, July 1997
3) Searches for First Generation Leptoquarks in the eeqq and enuqq channels, Federica Strumia, Allan Clark,Lorenzo Moneta, Xin Wu and Carla Grosso-Pilcher CDF/ANAL/EXOTIC/CDFR/4873
4) Description of data samples for Top and Electroweak groups for Winter 2003, Evelyn J. Thomson, CDF/DOC/TOP/PUBLIC/6265
5) Randall-Sundrum resonance searches in high mass Run I dilepton data, Tracey Pratt, Koji Ikado, Kaori Maeshima, Todd Huffman CDF/ANAL/EXOTIC/CDFR/6117
6) Search for Resonances in High Mass Dielectron Koji Ikado, Kuni Kondo, Kaori Maeshima, Tracey Pratt CDF/ANAL/EXOTIC/CDFR/6080
7) Event |Zvtx| < 60 cm Cut Efficiency for Run II W.K. Sakumoto and A. Hocker CDF/ANAL/ELECTROWEAK/CDFR/6331
8) Z^{0} to electrons Cross Section measurement with Run II data Young-Kee Kim, Giulia Manca CDF/ANAL/ELECTROWEAK/CDFR/6281
9) Trigger Efficiencies for High P_T Electrons Young-Kee Kim, Jason Nielsen, Lauren Tompkins, Greg Veramendi CDF/DOC/ELECTRON/CDFR/6234
10) http://www.thep.lu.se/~torbjorn/Pythia.html
11) http://mlm.home.cern.ch/mlm/alpgen/
12) http://consult.cern.ch/writeup/pdflib/
13) http://mcfm.fnal.gov/
14) Poisson Upper Limits Incorporating Uncertainties in Acceptance and Background John Conway Kaori Maeshima CDF/PUB/EXOTIC/PUBLIC/4476